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TRIP REPORT
SEVENTH INTERNATIONAL CONGRESS ON
APPLICATIONS OF LASERS AND ELECTRO-OPTICS
OCTOBER 31 - NOVEMBER 3, 1988, SANTA CLARA, CALIFORNIA

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Topics covered at the Seventh International Congress on Applications of Lasers and Electro-Optics (ICALEO) include carbon monoxide laser cutting of thick steels, laser welding to repair heat exchanger tubes, dual laser beam processing and high speed welding of steels. Information was also gathered on optical techniques for laser surface modification.

1. BACKGROUND

The International Congress on Applications of Lasers and Electro-Optics (ICALEO) is an annual event that comprises four conferences, dealing with laser materials processing, medical applications, flow diagnostics and optical sensing. This year for the first time ICALEO was part of OPTCON, which consists of a group of associated conferences along with a technical exhibition.

I attended the laser materials processing conference, which each year attracts approximately 100 researchers from around the world, including many of the recognized authorities in the field. It is generally acknowledged to be the premier North American event on the laser materials processing calendar. In spite of this, Tom Znotins of Lumonics and I were the only two Canadian attendees.

This year's conference lived up to expectations in the quality of both the participants and the presented papers. Nearly half the papers originated from European groups, with the rest split between the US and Asia. Most of the reported research was performed with the carbon dioxide (CO₂) laser, the workhorse of the industry. Only three of the 36 papers used the YAG laser and an equal number featured excimer lasers. It was noteworthy that many groups now have access to higher power CO₂ lasers - ten of the papers reported results obtained with power levels of 5 kW or more.

This report highlights some of the new applications of high power lasers presented at the conference, including the cutting of thick steels, targeted at the dismantling of nuclear power plants, and the welding of sleeves to repair heat exchanger tubes in steam generators. Other developments described

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are dual laser beam processing and a new technique for high speed welding. Information was also gathered on methods of laser surface treatment, which is being investigated at Ontario Hydro Research Division for hardening and improved corrosion resistance.

2. NEW DEVELOPMENTS

2.1 Carbon Monoxide Laser

A last minute substitute paper from the Industrial Research Institute in Japan proved to be an exciting addition to the conference. The Japanese are among the few groups around the world developing the 5 μm carbon monoxide (CO) laser as an alternative to the 10 μm CO₂ laser for materials processing, specifically for the cutting of thick steels.

The presenter, Dr. T. Fujioka, reported that a 3 kW CO laser is capable of cutting 7 to 8 cm thick mild steel and 3 to 4 cm thick stainless steel at 10 cm/min. Although the beam quality of the CO laser beam is not as good as that of a 3 to 5 kW CO₂ laser, the cutting performance for thick steels is far superior for reasons not yet fully understood. In addition to yielding nearly parallel cut edges the CO laser cuts at approximately twice the speed of the CO₂ laser. The end result is that the CO laser will be considered for thick section cutting applications that are not suitable for the CO₂ (see 3.1 below). It will be interesting to learn the capabilities of the recently developed 7 kW CO laser with >20% electrical efficiency for which no cutting data were presented. Dr. Fujioka also mentioned, in passing, his group's interest in using a >1 kW chemical laser with 40% electrical efficiency for materials processing.

2.2 Dual Beam Laser Processing

A new trend in laser materials processing is the use of two laser beams to improve cutting and welding performance. Professor W. Duley at York University is working on the forefront of this new technology, and last year we were involved with him in some preliminary studies using the PRC laser to assess the benefits of excimer laser pre-treatment in the CO₂ laser processing of aluminum and copper. These tests showed only marginal effects, probably because it is necessary to apply the two beams simultaneously to achieve the maximum benefit. This was clear from a paper by Professor W. Steen of the University of Liverpool who described research sponsored by Lumonics (UK). It appears that the effect is related to surface damage caused by the excimer laser which increases the coupling to CO₂ laser radiation, but a detailed model is yet to be developed. Professor Steen feels that if dual beam processing works well with the excimer laser it would be worthwhile assessing the CO₂ laser in combination with a cheaper laser like the YAG.

Dr. Fujioka of Japan also presented dual beam cutting data using a KrF excimer laser and the CO laser. The results show a doubling of the cutting speed for a given thickness of steel. Other combinations, such as the CO laser with a copper vapour laser, are also being tested.

It is worth noting that Professor Duley's research on dual beam processing is continuing and forms part of a proposal on laser materials processing being prepared by a group, including OHRD, for submission to the Federal Government's Networks of Centres of Excellence Program.

2.3 High Speed Laser Welding

One local company currently involved in laser processing is studying the pros and cons of using lasers to perform high-speed welding of steel in their manufacturing application. They will be very interested in a paper from the Fraunhofer Institute in Germany, outlining a novel approach to laser pipe welding, which promises to yield welding speeds ten times those of conventional laser welding. By using a vertically polarized laser beam, which is brought into the join area parallel rather than perpendicular to the direction of the weld

seam, the energy of the laser is coupled totally into the workpiece. I will be gathering more details on this process and passing them on to the Ontario manufacturer.

Two other papers, both from steel companies, dealt with high-speed laser welding. A Japanese group has compared TIG (tungsten inert gas) and CO₂ laser (5 kW) welding of stainless steel tubes with a wall thickness of 1 to 3 mm. Speeds of up to 15 m/min were achieved with the laser, twice those of TIG welding. The laser weld properties were excellent, showing greater toughness, better ductility and less cracking than TIG welds. A paper from Armco Steel in the US described the laser welding of automotive steels. Speeds up to 15 m/min were achieved with a 2.5 kW CO₂ laser, and all the usual tests showed excellent weld quality. Indications are that even though dissimilar metals are used (galvanized and normal steel), the laser welds are good enough that parts can be pressed to the required shape without further machining. A prototype production system is being planned for each of these processes.

3. NUCLEAR APPLICATIONS

3.1 CO Laser Cutting

The CO laser being developed in Japan (2.1 above), has as its ultimate objective the cutting of steels up to 30 cm in thickness for the decommissioning of nuclear power plants. The use of a laser for cutting such thick sections goes against conventional wisdom, so after the presentation I asked Dr. Fujioka what his reasons were. He cited the narrow kerf (cut width) of the laser cut compared to alternative methods, which results in improved safety because of lower fume production. Two other factors mentioned were the speed of the laser cutting process and the fact that it lends itself to automation. Dr. Fujioka did emphasize one disadvantage of CO compared to CO₂ lasers, namely the higher operating costs associated with the need to operate at lower temperatures (~100 K).

Should the CO laser cutting technology develop sufficiently rapidly, there is a possibility that it could be considered for the dismantling of Bruce Heavy Water Plant A, scheduled for the 1990's.

3.2 Laser Welding of Sleeves for Heat Exchanger Tubes

A group at Westinghouse has developed a technique for using laser welding to attach sleeves inside steam generator heat exchanger tubes used in nuclear reactors. Sleaving is a method of dealing with tube corrosion which, unlike plugging, allows the tube to remain in service. The traditional roll expansion technique of mechanically fixing the sleeve to the tube works adequately, but recently utilities have been demanding that sleeves be metallurgically bonded to the tube. Arc welding has been used but laser welding has many advantages including reduced distortion and a smaller heat affected zone.

The development of a laser welder for this application has involved several engineering projects, including the modularization of a commercial 1 kW CO₂ laser to make it readily transportable, and the invention of specialized optics and positioning equipment that permits welding from the inside up to 75 cm into a 16 mm diameter tube. Considering the geometrical constraints and the necessity to operate inside the confinement area, this is certainly an impressive technical achievement.

In the first field test of the system, 54 sleeves were recently installed at a Belgian utility. Negotiations are underway with a half dozen US utilities to come up with licensing arrangements. Under questioning, the presenter of the paper said he was not at liberty to discuss financial aspects of the technology.

4. OPTICAL TECHNIQUES FOR LASER SURFACE MODIFICATION

Tim Webber of Rofin-Sinar presented results of the laser hardening of small gears using a 2.5 kW CO₂ laser. The gears were 16 pitch, 25 mm diameter, and made of an alloy steel with a Rockwell C hardness (Rc) of 40. The processing time for the 16 teeth was 4s, giving a final surface hardness of Rc 64 and a case depth of 0.45 mm.

This paper was of particular interest because of a project we are undertaking for an Ontario auto parts manufacturer who has a need to harden selected areas of gear shift levers to a hardness which exceeds the normal limit imposed by the carbon content of the alloy steel. We are pursuing an approach described in the literature in which acetylene is dissociated by the laser beam to yield carbon, which enters the surface melt to increase the carbon content and hence the maximum hardness. Mr. Webber felt that this was a technique worth investigating and suggested introducing the carbon via graphite powder placed on the surface prior to laser processing. He also cautioned that if there is a large difference between the hardness of the core and of the surface layer, the latter may break away under impact. It may be necessary to slightly harden the core to generate a less steep hardness gradient.

The energy distribution in most laser beams is uneven, with the maximum energy at the center of the beam. For uniform surface modification it is necessary to even out the energy distribution in some manner. For the past several months I have been gathering information on optical techniques for accomplishing this, since our plans for 1989 involve a good deal of surface modification studies, including hardening and alloying. In this connection we recently purchased a scanner to oscillate the focused beam over the metal surface. Another approach, which we will also be evaluating, is to use an optical integrator to render the energy distribution across the beam relatively uniform. At the conference, Stan Ream of Amada, one of the pioneers of laser materials processing, was kind enough to sketch out a design for an optical integrator which consists of a polished copper light pipe with lenses on either end. An optics company I encountered at the technical exhibit could build one for us or alternatively we could have it built in our model shop.

Spawr presented a paper on their segmented-mirror optical integrator which is used for the same purpose. This is the company that a few years ago ran afoul of the US Department of Commerce and were slapped with a ban on export, which is expected to be lifted within a few months. Spawr claims that their integrator is better than Ream's light pipe because with the latter 50% of the energy is lost in transmission. Dr. Ream told me that with proper design the transmission is >80% and that the beam energy is more evenly distributed than with Spawr's integrator. Based on discussions with both sides, I have more confidence in Dr. Ream's conclusions.

5. OTHER TOPICS

I was asked by one laser user to gather information at the conference on the expected lifetime of the blower in high power CO₂ lasers, which is needed for their assessment of laser processing. I found that the range of blower lifetimes is too broad to assign a single value - in some cases they last more than 10 000 hours, in others they fail after only 500 hours. One ICALEO participant stated that the main problem was not replacing the blower but rather dealing with the side effects of a failure such as oil being deposited on the optics. In this regard he claimed that the blowers in Rofin-Sinar lasers were designed to avoid this problem. Another message was that pre-1986 blowers were poorly designed but for lasers shipped within the past two years, the blowers should last several thousand hours. PRC has recently developed a turbine to replace the blower in their lasers; this will be available within a few months following extensive field testing and should result in significantly lower maintenance costs.

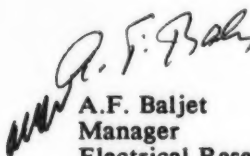
In addition to the novel approach to high-speed welding (section 2.3), the Fraunhofer Institute in Germany presented two other impressive papers. The first described experiments on the CO₂ laser welding of aluminum which, if properly designed, can be done faster than steel. The key factor is the flow rate of the nitrogen assist gas. The second paper reported progress on the theory of laser cutting, specifically cutting with inert gas rather than oxygen assist. Use of high pressure nitrogen rather than oxygen is the secret of Amada's "clean cut" process whose dross-free, weld-ready edge has been heavily promoted during the past year. Stan Ream of Amada congratulated the developers of the theory, calling it the most workable, realistic model he had seen in fifteen years.

SUMMARY

Several new developments were apparent at this year's ICALEO laser materials processing conference. In Japan, the carbon monoxide laser is being applied to thick section metal cutting, aimed at eventually dismantling nuclear power plants. *In situ* laser welding of sleeves for the repair of steam generator heat exchanger tubes has been developed in the US. Dual laser beam processing is being studied at several laboratories to enhance the effectiveness of laser cutting and welding. German researchers have made a dramatic breakthrough in the high-speed laser welding of steel pipe.

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